Results from Borexino phase I and future plans of the experiment

DPG Frühjarstagung 2014 – Mainz

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

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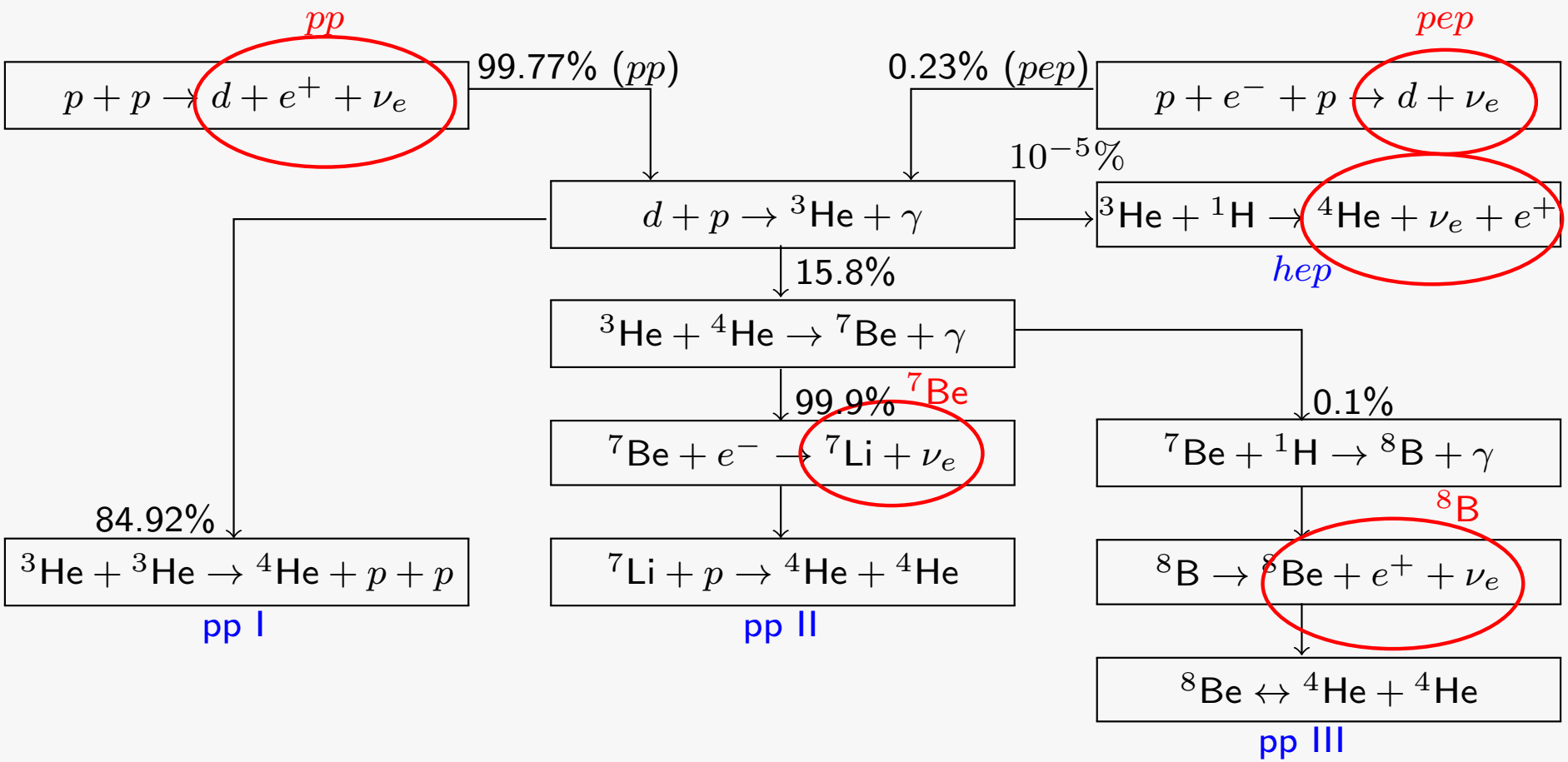
Overview

Solar Neutrinos: pp-chain

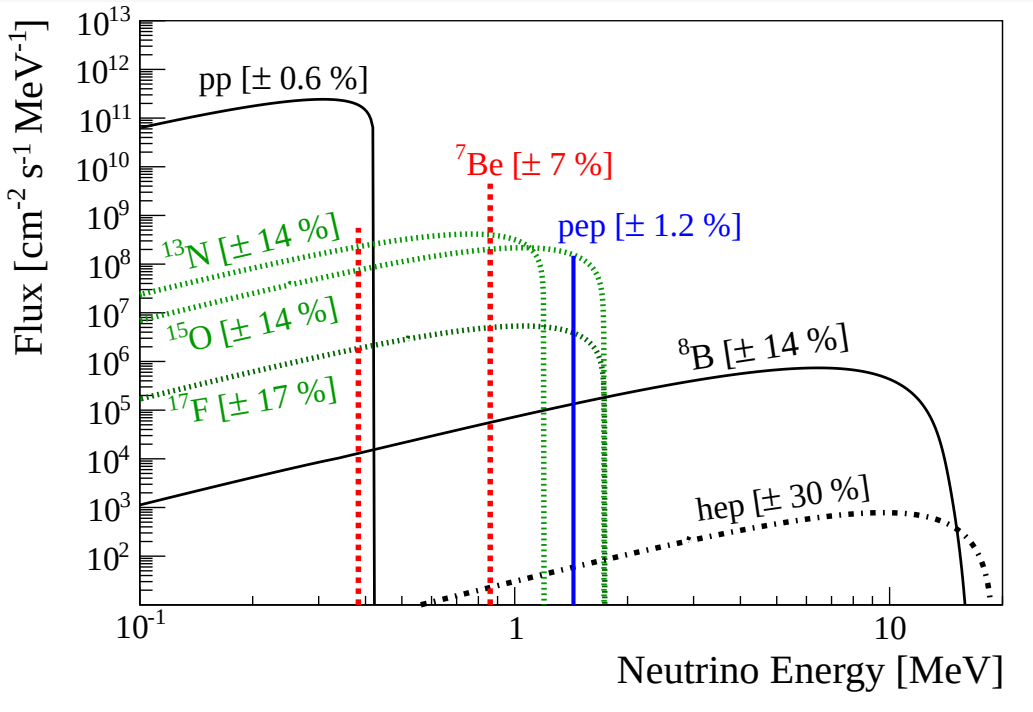
- Energy Production in the Sun: Fusion
- $4p \rightarrow {}^4\mathrm{He} + 2e^+ + 2\nu_e + 26.7\ \mathrm{MeV}$
- Main contribution: pp-chain



Solar Neutrinos: CNO-cycle / Neutrino Spectrum

CNO I:

$$
\begin{aligned}
{}^{12}\mathrm{C} + {}^{1}\mathrm{H} &\rightarrow {}^{13}\mathrm{N} + \gamma \\
{}^{13}\mathrm{N} &\rightarrow {}^{13}\mathrm{C} + e^{+} + \nu_e \\
{}^{13}\mathrm{C} + {}^{1}\mathrm{H} &\rightarrow {}^{14}\mathrm{N} + \gamma \\
{}^{14}\mathrm{N} + {}^{1}\mathrm{H} &\rightarrow {}^{15}\mathrm{O} + \gamma \\
{}^{15}\mathrm{O} &\rightarrow {}^{15}\mathrm{N} + e^{+} + \nu_e \\
{}^{15}\mathrm{N} + {}^{1}\mathrm{H} &\rightarrow {}^{12}\mathrm{C} + {}^{4}\mathrm{He}
\end{aligned}
$$



CNO contribution to our Sun's energy production $< 1\%$

Main contribution for heavier stars

Neutrino Detection in Liquid Scintillator

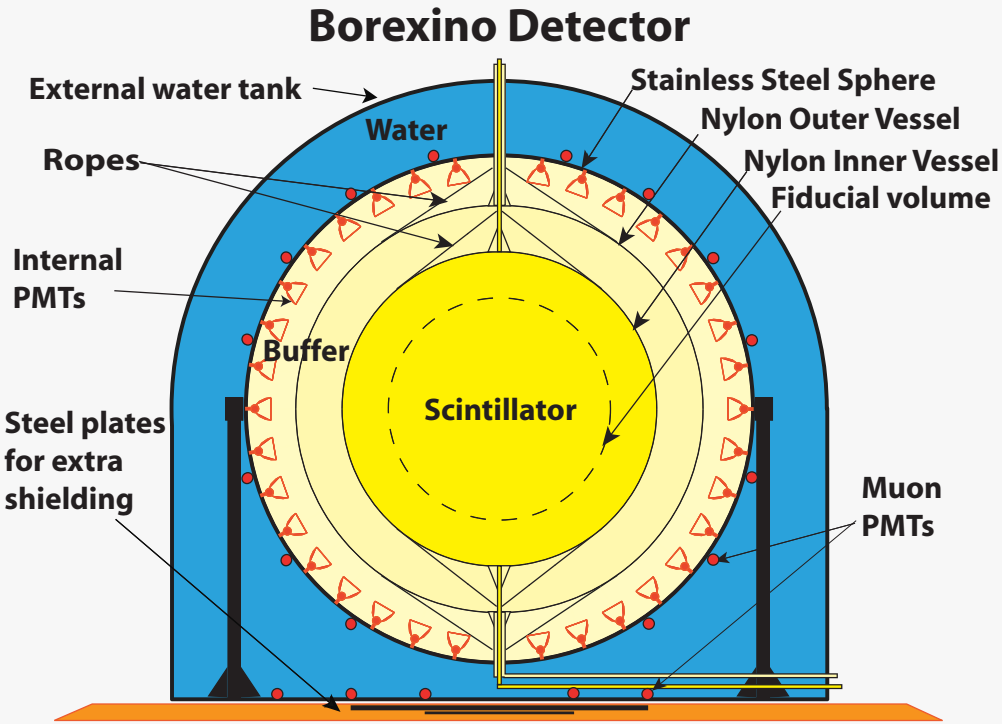
Neutrinos

- Neutrino electron scattering
- Scintillation light produced by recoil electron
- Compton like energy transfer
- No energy threshold (limited by $^{14}\mathrm{C}$ background (156 keV))

Antineutrinos

- Inverse β-decay ($p + \bar{\nu}_e \rightarrow e^+ + n$)
- Annihilation of positron
- Delayed neutron capture on Hydrogen: $\mathrm{H} + n \rightarrow d + \gamma(2.2\,\mathrm{MeV})$
- Energy threshold: 1.806 MeV

Borexino Detector Setup



Steel dome: ⌀18 m – 16.9 m high

Inner Detector

Graded shielding

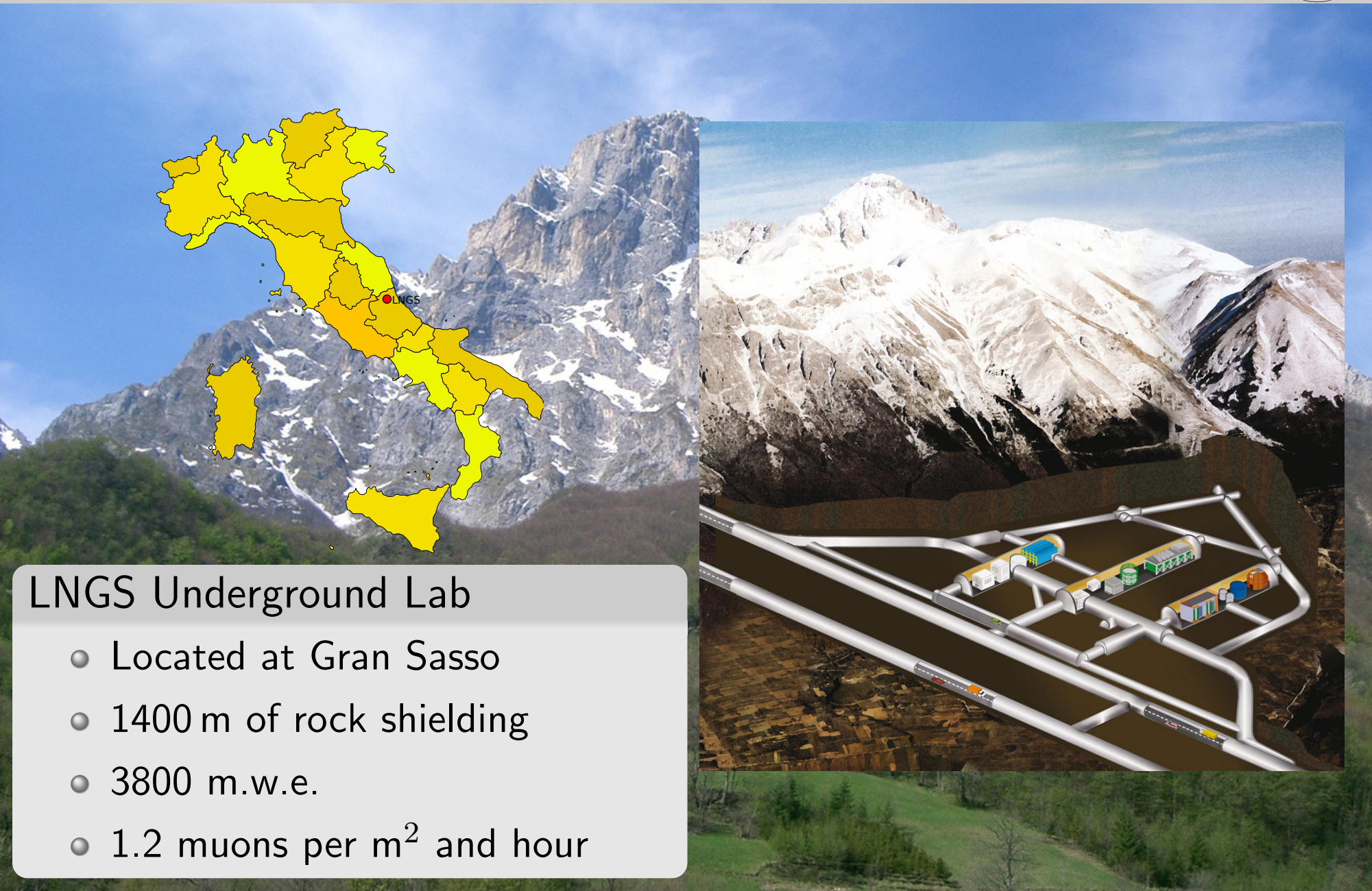
- 278 tons pseudocumene
- $\sim 1.5\,\mathrm{g}/\ell$ PPO
- Two 125 µm nylon vessels (⌀8.5 m and 11 m)
- Barrier against radon
- Buffer: light quencher DMP
- Stainless steel sphere (⌀13.7 m)
- 2212 inward facing 8" PMTs

Outer Detector

2100 tons ultra pure water

- Active shielding
- 208 PMTs ⇒ Cherenkov veto

Borexino Detecor Site



LNGS Underground Lab

- Located at Gran Sasso
- 1400 m of rock shielding
- 3800 m.w.e.
- 1.2 muons per m^2 and hour

Data Taking Campaign

Phase I – May 2007 - May 2010

- First observation of $^{7}\mathrm{Be}$ neutrinos
- Day-night asymmetry
- $^{8}\mathrm{B}$ neutrinos
- pep neutrinos
- Limit on CNO
- geo-neutrinos
- Muon seasonal variations
- Limits on rare processes

Purification campaigns

- May 2010
- Aug-Oct 2011

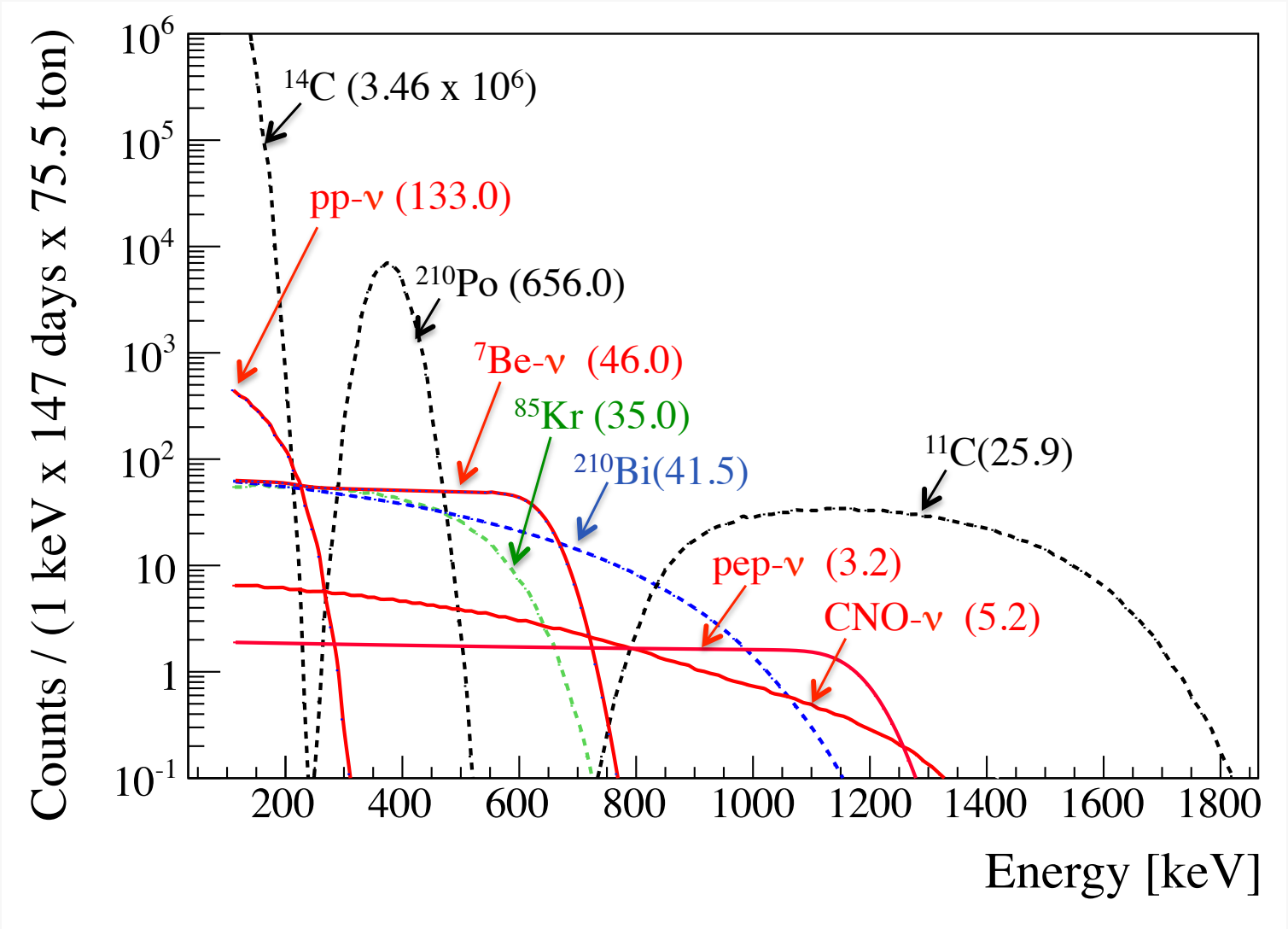
Phase II – ongoing

- pp neutrinos
- CNO neutrinos
- Short baseline oscillations (SOX)

All phases

Neutrons and other cosmogenics, $^{7}\mathrm{Be}$ seasonal variations, update on geo-ν

Expected Signal and Major Background



^{7}Be Interaction Rate

Rate

$$46.0 \pm 1.5(\text{stat})^{+1.5}_{-1.6}(\text{sys})/\text{d} \cdot 100\text{t}$$

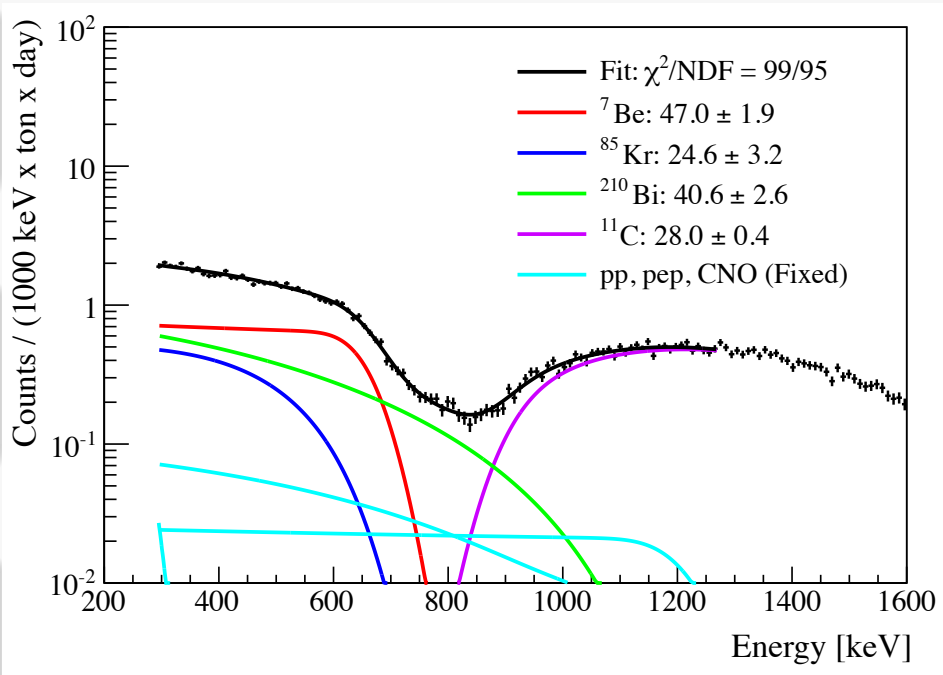
Flux

$$\phi_{\text{Be}} = (3.10 \pm 0.15) \times 10^9 \text{ cm}^{-2}\text{s}^{-1}$$

Survival Probability

$$P_{ee} = 0.51 \pm 0.07 \quad \text{at} \quad 0.862\,\text{MeV}$$

741 days:

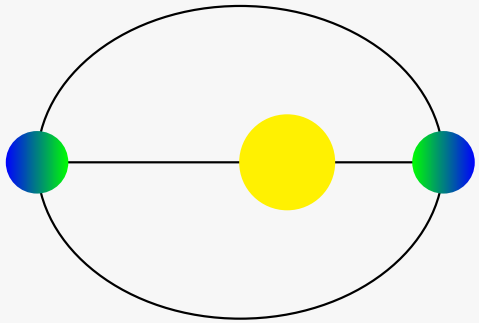


Phys. Rev. Lett. 107 (2011) 141302

^{7}Be Day-Night Assymetry excluded (Phys. Lett. 707, 1 (2011) 22-26)

$$A_{DN} = \frac{N - D}{(N + D)/2} = 0.001 \pm 0.012(\text{stat}) \pm 0.007(\text{sys})$$

^{7}Be ν-flux Annual Modulation

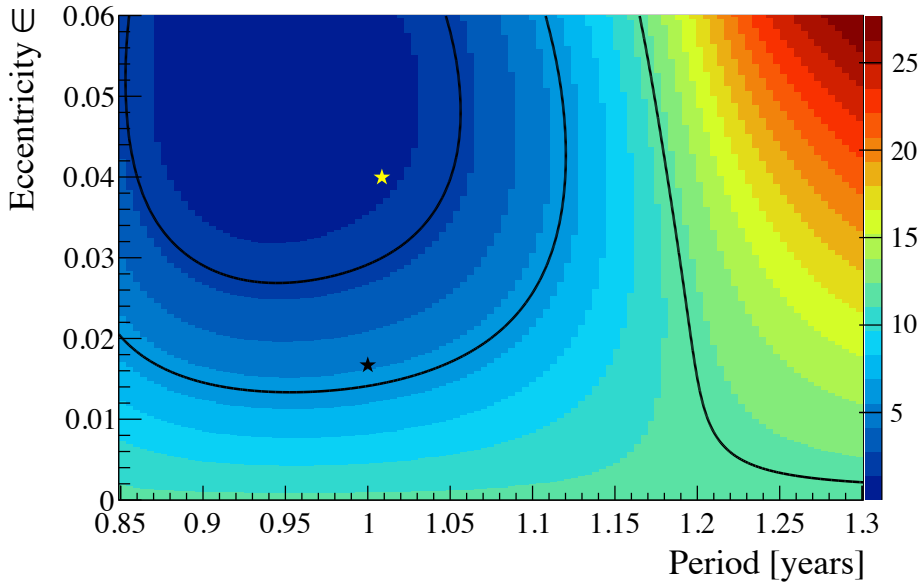


- Earth eccentricity $\varepsilon = 0.0167$
- Sinusoidal flux variation in time
- 7 % variation of peak amplitude

$$R(t) = \bar{R}\left[1 + 2\varepsilon\cos\left(\frac{2\pi t}{T} - \phi\right)\right]$$

Three Analyses

- Rate fit vs. time
  including background evolution



- Lomb Scargle method
- Empirical Mode Decomposition

No evidence for anomalous oscillations at 3 σ (arXiv:1308.0443)

^{8}B Neutrino Flux

Rate $E > 3$ MeV

$0.22 \pm 0.04(\text{stat}) \pm 0.01(\text{sys})/\text{d} \cdot 100\text{t}$

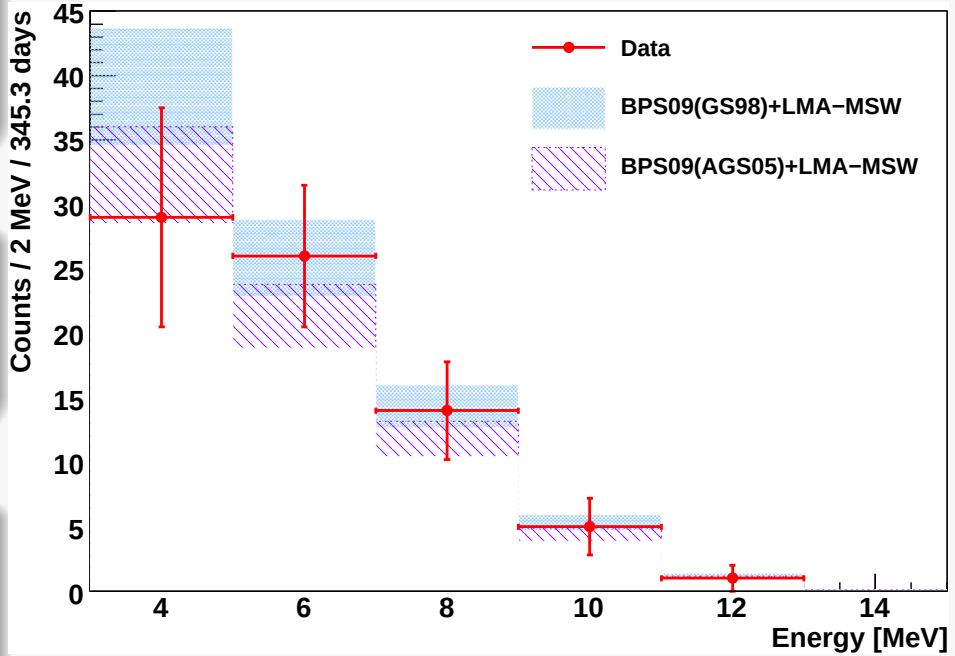
Flux

$\phi_{\text{B}} = (2.4 \pm 0.4 \pm 0.1) \times 10^6 \ /\text{cm}^2\text{s}$

Survival Probability

$$P_{ee} = 0.29 \pm 0.10$$

at $< E >= 8.9\,\text{MeV}$



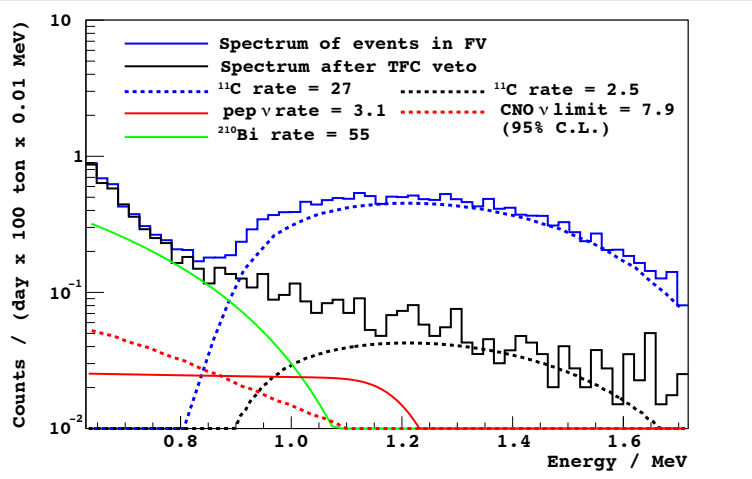
Phys.Rev. D82 (2010) 033006

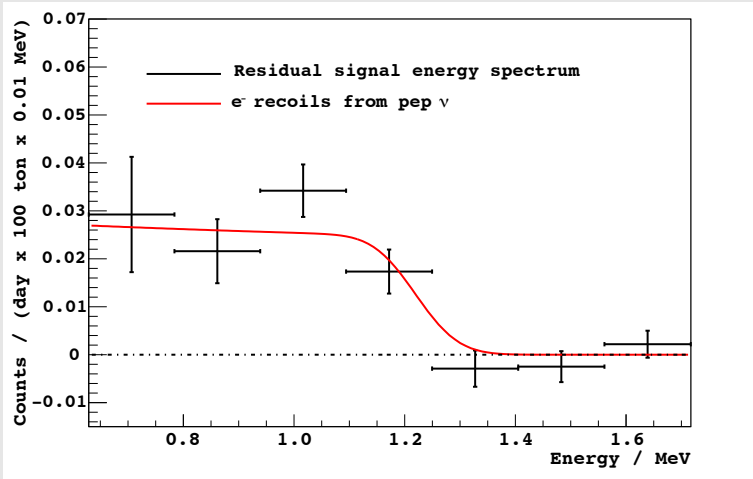
Simon Appel – T 40.2, Mo, 17:05–17:20

Update on the ^{8}B neutrino analysis in Borexino

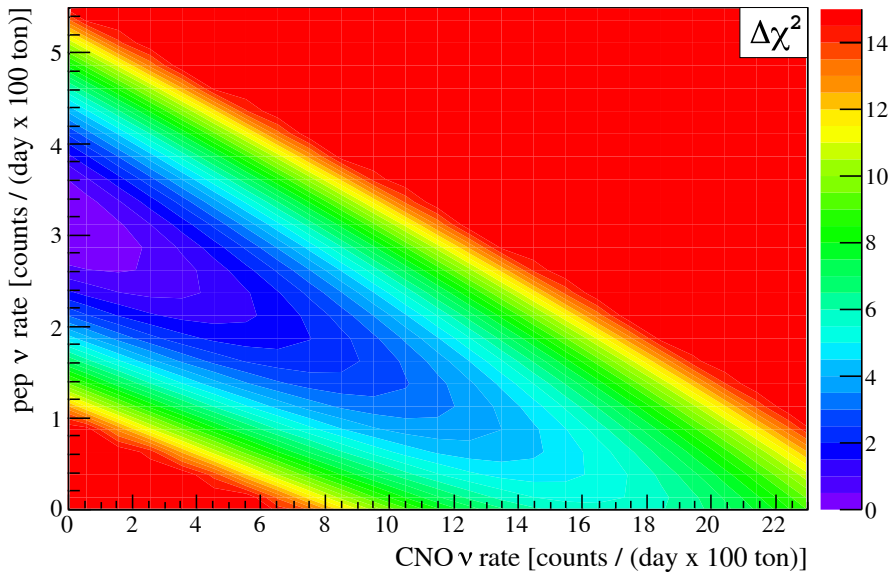
pep and CNO neutrino fluxes

First measurement of *pep* solar neutrino rate (Phys. Rev. Lett. 108 (2012) 051302)

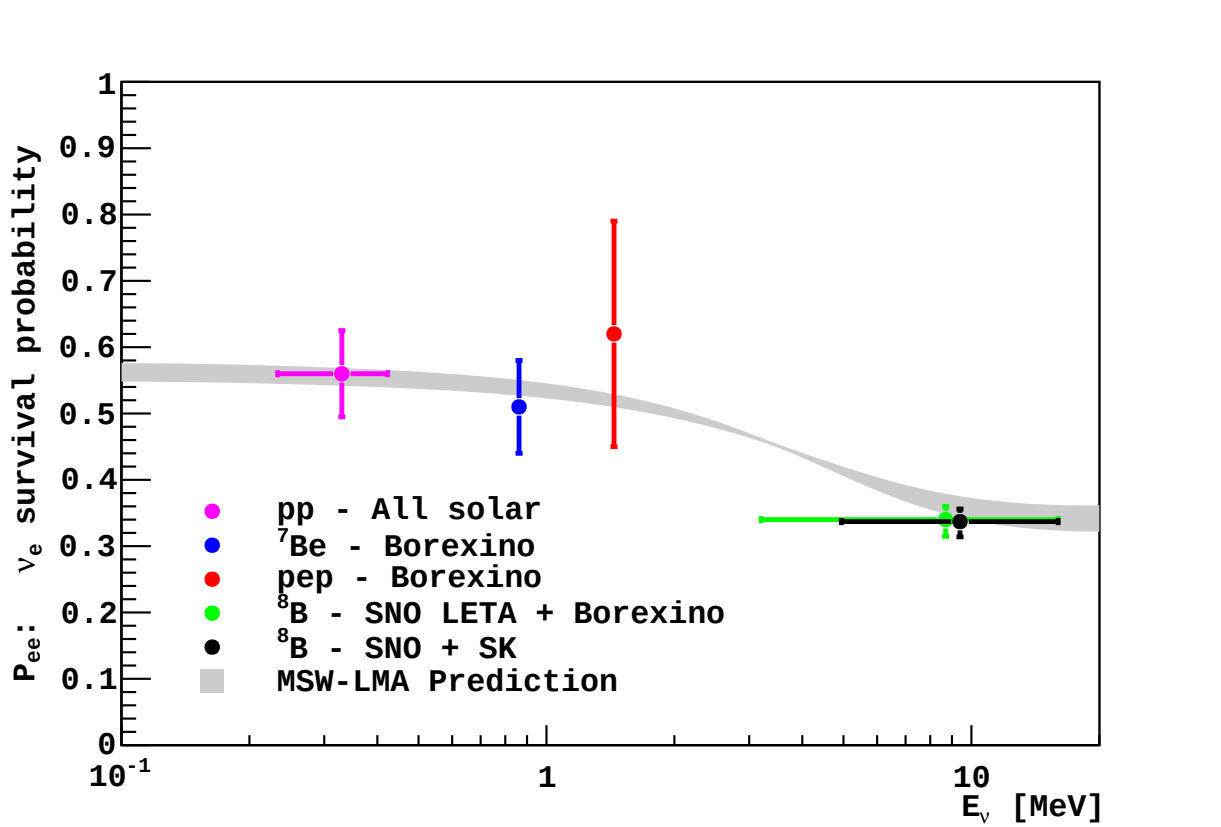




- $R = (3.1 \pm 0.6 \pm 0.3)\,\mathrm{cpd/100\,t}$
- $\phi = (1.6 \pm 0.3) \times 10^{18}\,\mathrm{cm^{-1}s^{-1}}$
- $P_{ee} = 0.62 \pm 0.17$ at 1.44 MeV
- Strongest limit on CNO solar neutrino rate
- $\phi_{\mathrm{CNO}} < 7.7 \times 10^{8}\,\mathrm{cm^{-1}s^{-1}}$



P_{ee} after Borexino



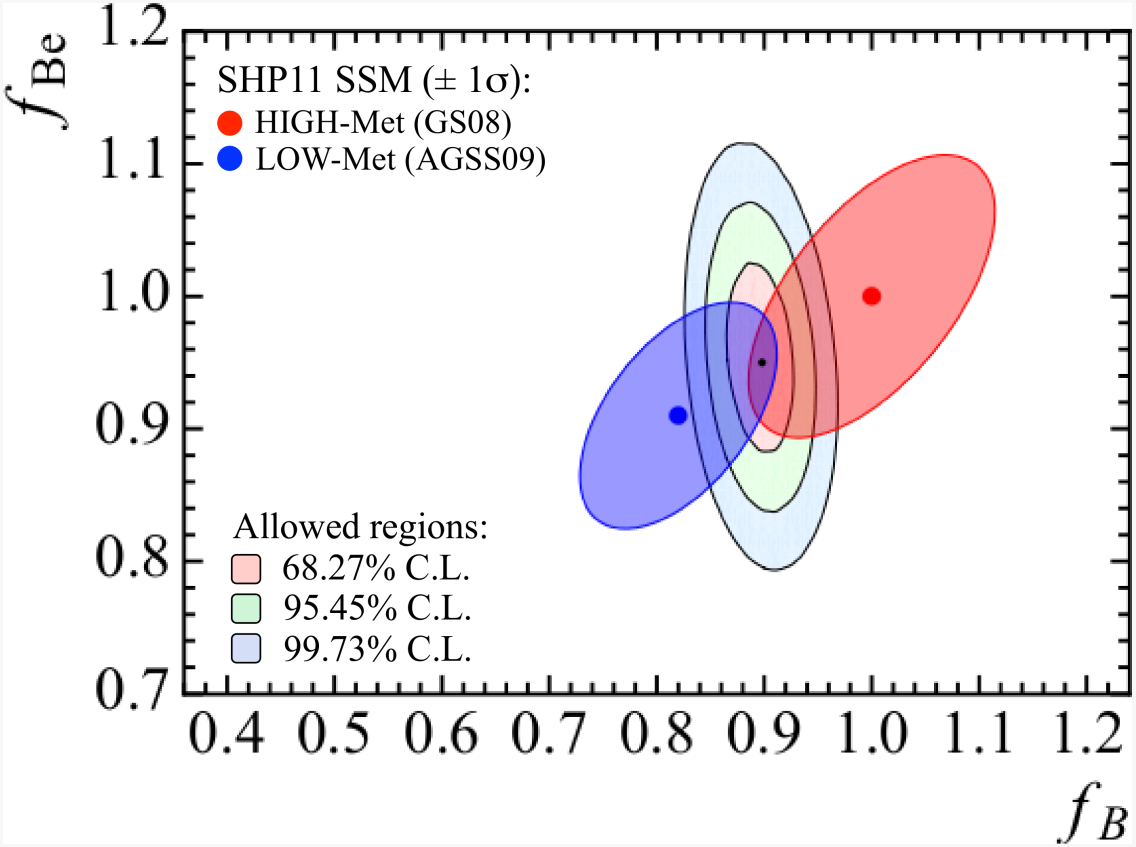
transition region of MSW effect

- Reduce error on $pep - \nu$ flux
- Lower threshold on $^8\mathrm{B} - \nu$

$\Rightarrow$ Phase II

SSM Metallicity

arXiv:1308.0443



Reduced flux

$$f_i = \frac{\phi_{\text{true}}}{\phi_{\text{SSM}}}$$

High metallicity hypothesis:

- $f_{\text{Be}} = 1.00 \pm 0.07$
- $f_{\text{B}} = 1.00 \pm 0.14$

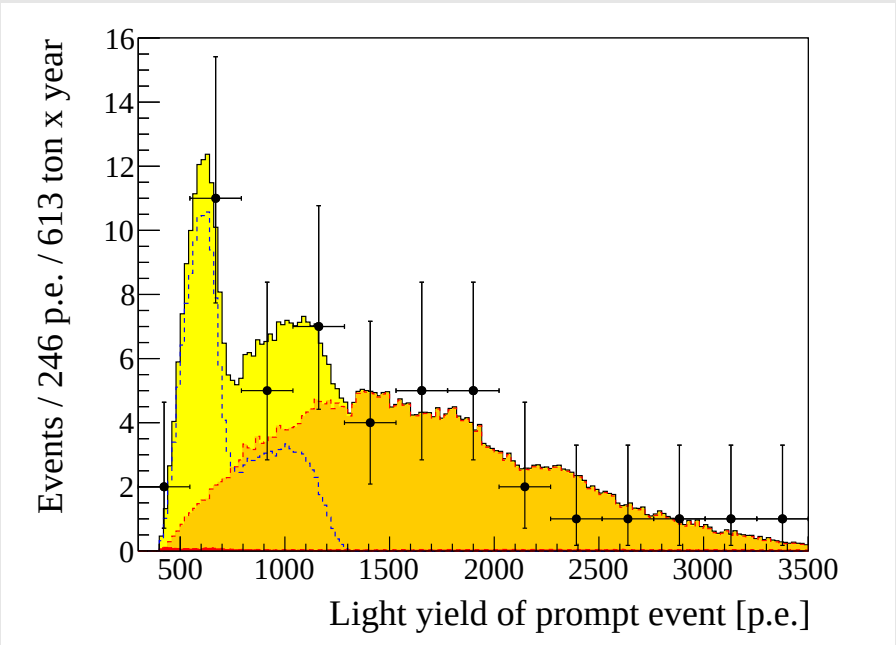
Low metallicity hypothesis:

- $f_{\text{Be}} = 0.91 \pm 0.06$
- $f_{\text{B}} = 0.82 \pm 0.11$

- ^{7}Be and ^{8}B data cannot discriminate models
- $\Rightarrow$ CNO measurement needed! Phase II!

Geo-neutrinos

Data from 1353 days



PLB 722 (2013) 295-300

- 46 *golden* coincidences
- $\mathrm{Th/U}$ fixed to chondritic value of 3.9 or as free parameter
- Null geo-ν excluded, 6×10^{-6} probability
- $31.2^{+7.0}_{-6.1}$ reactor $\bar{\nu}$ events consistent with expectations

$1\,\mathrm{TNU} = 1\,\mathrm{event}/10^{32}\,\mathrm{protons/year}$

Fixed $\mathrm{Th/U}$

$$N_{\mathrm{geo}} = 14.3 \pm 4.4\,\mathrm{events}$$

$$S_{\mathrm{geo}} = 38.8 \pm 12.0\,\mathrm{TNU}$$

$\mathrm{Th/U}$ free in fit

$$S_{^{238}\mathrm{U}} = 26.5 \pm 19.5\,\mathrm{TNU}$$

$$S_{^{232}\mathrm{Th}} = 10.6 \pm 12.7\,\mathrm{TNU}$$

SOX

JHEP 08 (2013) 038

SOX A

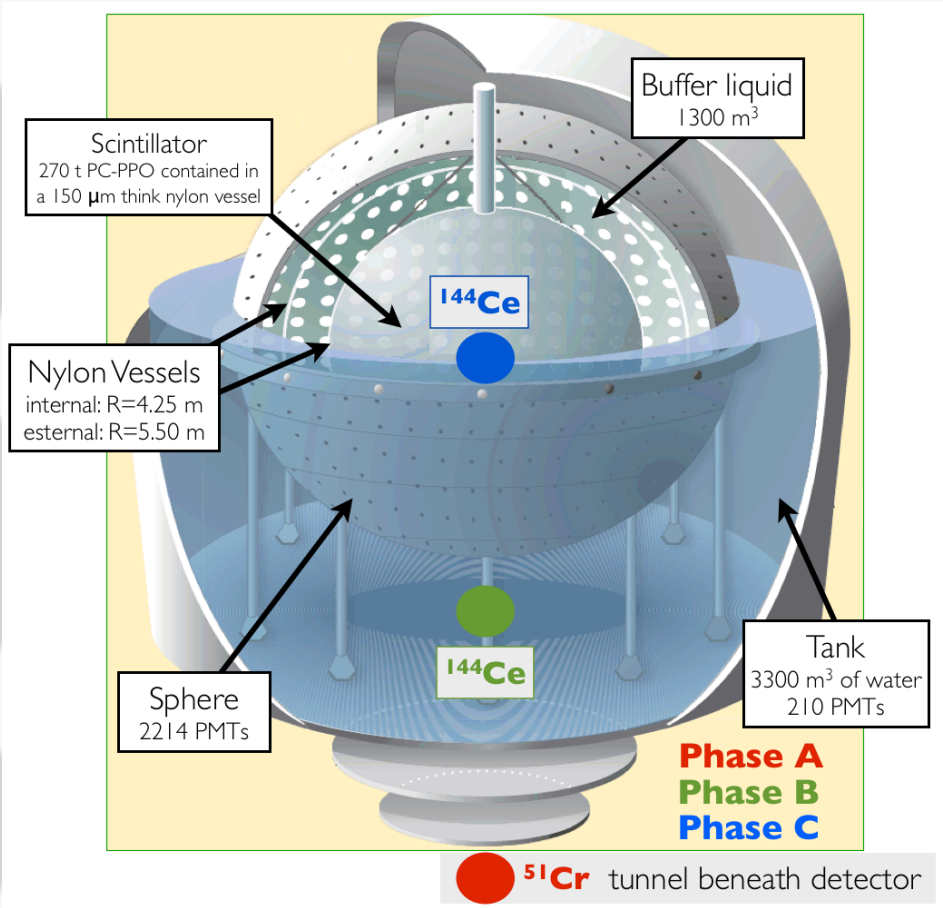
- $^{51}\mathrm{Cr}$ Source
- Tunnel underneath detector

SOX B

- $^{144}\mathrm{Ce}$ Source
- Inside water tank

SOX C

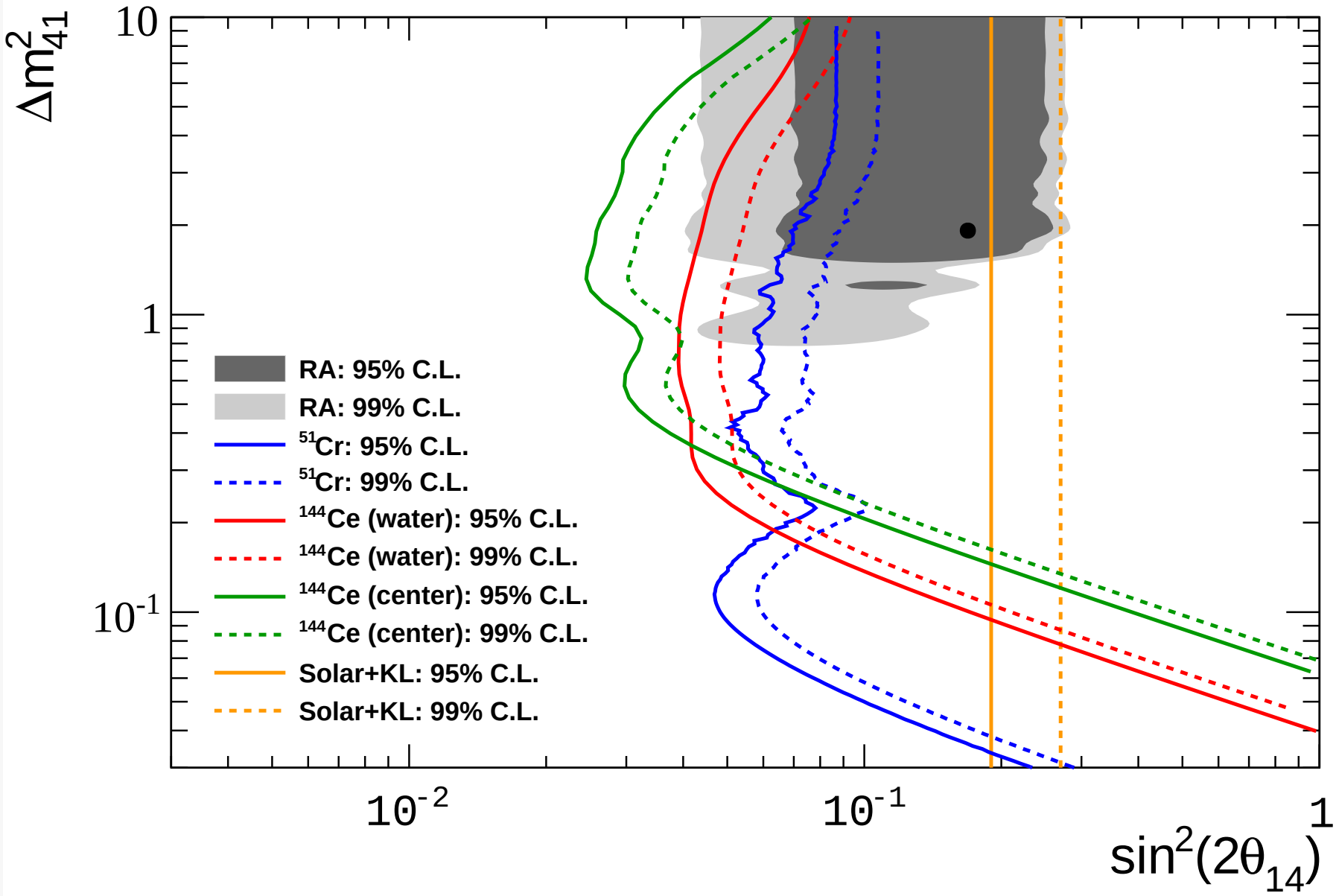
- $^{144}\mathrm{Ce}$ inside scintillator



Mikko Meyer – T 101.3, Do, 17:15–17:25

Gruppenbericht: Search for new physics with SOX

SOX: Sensitivity



Phase II program

- pp neutrino flux measurement (2014)
- Precision pep neutrino measurement ($> 3\sigma$) (2015)
- Measurement or stronger limits on CNO (2015)
- $^{7}\mathrm{Be}$ neutrino flux at 3% (2016-17)
- Geo-neutrinos with higher statistics (2016-17)
- $^{8}\mathrm{B}$ neutrino flux with $4\times$ higher statistics (aiming 10%) (2016-17)
- SOX (SOX-A 2015, SOX-B,C 2016-17)
  - search for sterile neutrinos
  - measurement of neutrino magnetic moment
  - search for non standard ν interactions

Conclusions

- Data taking for almost seven years
- Unprecedented radiopurity
- Broad range of solar ν fluxes (^{7}Be, ^{8}B, pep, CNO) and geo neutrinos
- Now in phase II, improve measurements and look for pp
- SOX will test reactor antineutrino anomaly

Borexino Talks @ Mainz 2014

Simon Appel – T 40.2, Mo, 17:05–17:20

Update on the $^{8}\mathrm{B}$ neutrino analysis in Borexino

Dominikus Hellgartner – T 40.4, Mo, 17:40–17:55

Application of the Backtracking-Algorithm to muons in Borexino

Mikko Meyer – T 101.3, Do, 17:15–17:25

Gruppenbericht: Search for new physics with SOX